Performance Evaluation of Makeshift Solar Cabinet Dryers for Drying Roselle

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***Abstract*—Myanmar has good solar resource potential, having Global Horizontal Irradiation (GHI) levels of between 1,600 and 2,000 kWh/m^2/yr., and average Direct Normal Irradiation (DNI) levels of about 1,400 kWh/m^2/yr. In Myanmar, people enjoy consuming vegetables in daily diet. However, there is almost no post-harvest technology resulting in nutritional and economic losses during season. Solar drying technology is one of the most promising alternatives to reduce the postharvest losses.**

The solar cabinet drying system was designed and constructed to operate on the principle of convective heat flow. The design is the indirect type passive solar drying system to dry agriculture products inside the dryer. The absorber plate of the solar collector attained a temperature of an average 65°C during daylight condition whilst inside the dryer of 55°C. The thermal performance of the solar collector was found to be poor because of low convective heat transfer from absorber to air. From the anemometer reading the air velocity inside the dryer was found to be 0.1 ms^{-1}. The efficiency of the dryer design was determined by pick-up efficiency, collection efficiency and system drying efficiency.

The distributed (indirect type) solar cabinet dryer (DSCD) was modified into forced convection solar cabinet dryer. An indirect forced convection solar cabinet dryer integrated with sensible heat storage material (pebbles) had been developed and tested its performance. In addition, the system consists of air blower to induce forced air circulation. The average air velocity is 0.5 ms^{-1} and the maximum absorber temperature of 70^{o}C and chamber temperature of 50^{o}C. The performance evaluation of forced convection solar cabinet dryer (FCSCD) was computed and compared to with DSCD. The results showed FCSCD had significant ($p<0.05$) than the other three methods in moisture reduction.

The physico-chemical characteristics, minerals and heavy metals constituents and rehydration ratios of dried roselle were determined and compared with fresh and commercial products. Water activity and microbiological examination of dried products were also performed to extend shelf life of dried products. The shelf life of three months observed for dried products. Fresh samples were also investigated residual pesticides to assure toxic substances in dried products for consumer safety. The organoleptic properties of rehydrated products were also determined by the 9-point Hedonic Scale Rating Test. The information and knowledge that will be generated from the study will serve to produce the traditional products from locally available raw materials, which include dried food products.

Key words: DSCD, FCSCD, pick-up efficiency, collection efficiency, system drying efficiency

Abbreviations

°C	Degree Celsius
dia.	diameter
DSCD	Distributed Solar Cabinet Dryer
FCSCD	Forced Convection Solar Cabinet Dryer
g	gram
hr.	hour
in	inch
K	kelvin
kg	kilogram
kJ	kilojoule
kWh/m^2/yr.	kilowatt hour per meter square per year
m	meter
min.	minute
ml	milliliter
mm	millimeter
%	percent
ppm	parts per million
SD	Sun Drying
s	second
TD	Tray Dryer

I. INTRODUCTION

Myanmar is an agricultural country well-endowed with land, a generally favorable climate and plentiful water resources for agricultural production [1]. However, despite their nutritional and health benefits, many fruits and vegetables are highly seasonal and perishable resulting into huge postharvest loss. Solar drying is a simple inexpensive form of food processing that has greater potential to reduce the post-harvest losses and ensure the availability of perishable products like fruits and vegetables all year round [2].

Roselle (*Hibiscus sabdariffa* L.), Myanmar name Chin Baung is an annual herbaceous shrub belongs to Malvaceae family. Roselle, native to West Africa and it is cultivated in warm countries [3]. Roselle is considered as one of the important medicinal plant in some parts of the world [4]. Many parts of roselle including seeds, leaves, fruits and roots are used in various foods. The young leaves and tender stems of roselle are eaten raw in salads or cooked as greens alone or in combination with other vegetables and/or with meat. They are also added to curries as seasoning. Roselle is a popular and common indigenous leafy vegetable grown all over the Myanmar. It is eaten green and fresh or dried and stored for future use [5].

II. MATERIALS AND METHODS

A. Raw Materials

Roselle (*Hibiscus sabdariffa* L.)was purchased from Hmawbi Township, Yangon Region. Sodium metabisulphite and ascorbic acid were purchased from Shwema Chemical Shop, Pabeden Township, Yangon Region.

B. Methods

The Experimental Setup

The materials used for the construction of dryer were inexpensive and easily obtainable in the local market. The essential features of the dryer consist of the solar collector, drying cabinet and drying trays.

The experimental setup was a corrugated galvanized iron sheet which was painted black to enhance the absorbing capacity was used as heat absorber. Glass 0.197″× 48″ × 26″ was used as the solar collector cover and heat absorber. The base of the collector was vented to allow the entrance of air to be heated for drying. The collector slope was 31.54° from the horizontal. The collector area was 0.085 m².

The drying cabinet was constructed with 6mm thick plywood as wall and cover and 1 in. sq. metal alloy pipe was used as frame. Inside the dryer, 4mm thick insulation foam was used to prevent heat loss. The area of drying cabinet was 0.036 m². Inside the drying chamber, 8 drying trays were contained and constructed 4mesh screen. The trays were separated with a gap of 3 in.

The distributed (indirect) solar cabinet dryer (DSCD) was modified into forced convection solar cabinet dryer integrated with pebble bed as heat storage unit. The solar collector of FCSCD was constructed 0.5-0.8 in. pebbles which were painted black to absorb the solar radiation and as heat storage unit. Glass 0.197″× 48″ × 26″ was used as the solar collector cover and heat absorber. At the top of the collector an electric fan was assembled to get the air of forced convection through the dryer and at the back (outside) of the collector a metal pipe of 2″ dia. was fixed with the fan to circulate the hot air from the collector to the dryer.

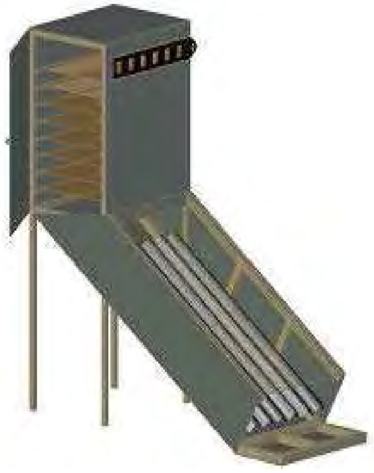

Figure (1) Isometric View of Distributed Solar Cabinet Dryer

Figure (2) Isometric View of Forced Convection Solar Cabinet Dryer

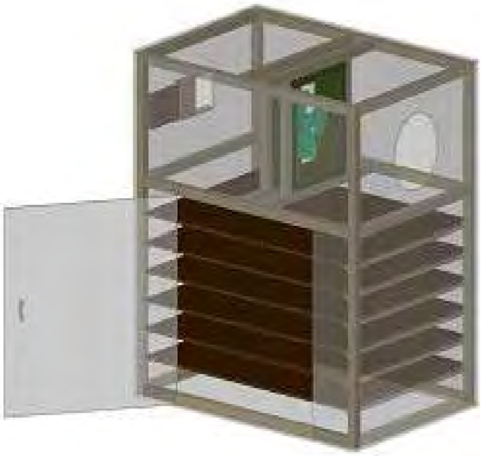

Figure (3) Isometric View of Tray Dryer

Evaluation of Solar Dryer's Thermal Performance

The measurement of solar intensity was obtained from the solar electricity handbook [6]. The ambient temperature was measured by thermometer and dry bulb and wet bulb temperatures were measured by dry bulb and wet bulb thermometer or psychrometer. Air velocity through the dryer was measured by digital anemometer. The relative humidity in the dryer was measured by digital hygrometer and absolute humidity was measured from psychrometric chart. The data of daily relative humidity and ambient air velocity was obtained from Department of Meteorology and Hydrology, Kaba-Aye Station.

For System Drying Efficiency:

$$\eta_d = \frac{W\ \Delta H_L}{I_d\ A_c}$$

Where, W = moisture evaporated, kg, H_L = latent heat of vaporization of water, 2320 kJ /kg, I_d = total daily insolation incident upon collector, A_c = area of collector, m²

For Collection Efficiency:

$$\eta_c = \frac{v\,\rho\,\Delta T\,C_p}{A_c\,I_c}$$

Where, v = volumetric flow rate of air, m^3s^{-1}, ρ = air density, kgm^{-3}, ΔT = air temperature elevation, °C, C_p = air specific heat, $Jkg^{-1}K^{-1}$, A_c=area of collector, m², I_c = insolation on collector surface, $W\ m^{-2}$

For Pick-up Efficiency:

$$\eta_p = \frac{W}{v\rho t\ (h_{as} - h_i)}$$

Where, W = moisture evaporated, kg, v = volumetric air flow rate, m^3s^{-1}, ρ = air density, kgm^{-3}, t = drying time, s, h_{as} = adiabatic saturation humidity, h_i = absolute humidity of inlet air[7]

For Drying Rate:

$$\text{Drying Rate} = \frac{W_\theta - W_{\theta+\Delta\theta}}{A\,\Delta\theta}$$

Where, W_θ= Weight of total moisture in the sample at time θ, $W_{\theta+\Delta\theta}$= Weight of total moisture in the sample at time θ + Δθ, A = Area of sample exposed to drying [8].

Preparation of Dried Roselle

Fresh and sound roselle leaves were plucked from plant parts and washed thoroughly with water to remove soil, dirt and pesticide residues. Any of the bruise and withered leaves was removed during washing and then the washed leaves were drained to remove excess water. 200g of cleaned roselle leaves were evenly spread on the trays of distributed solar cabinet dryer (DSCD) at temperature ranging from 35-65°C, in forced convection solar cabinet dryer (FCSCD) at temperature ranging from 35-60°C and in tray dryer (TD), the temperature was calibrated at 50±4°C. For sun drying, 200g of roselle leaves were spread on the plastic sieve trays and then sun dried. All samples were weighed at an interval of 30 minutes. After drying processes have taken place, dried roselle leaves were put into the air-sealed plastic boxes and stored in a dry and place away from direct sunlight. The organoleptic properties, physico-chemical properties and nutritional value, minerals and heavy metals composition, water activity and microbiological analysis of dried roselle were determined and results are recorded in Tables (7), (9), (10), (11) and (12).

Effect of Food Additives on Drying of Roselle

The effects of concentration of sodium metabisulphite solution, ascorbic acid solution, sodium bicarbonate solution and immersing time on the drying of roselle were investigated. Organoleptic properties and shelf-life were determined and the results are recorded in Table (2) to (6).

III. RESULTS AND DISCUSSION

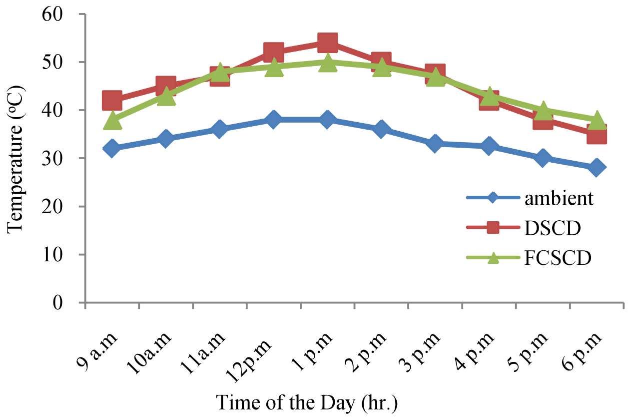

Figure (4) Diurnal Variation of the Temperature during the Experiment

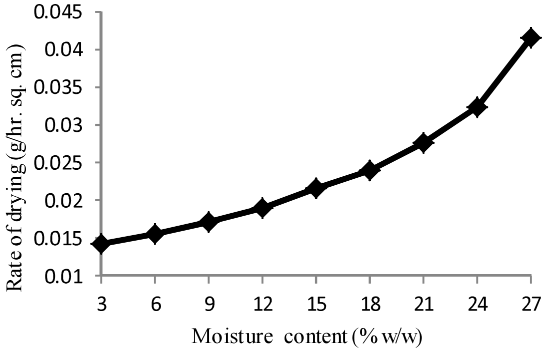

Figure (5) Drying Rate Curve of Roselle using Distributed Solar Cabinet Dryer

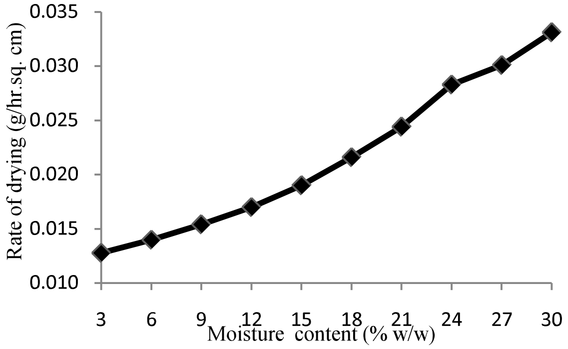

Figure (6) Drying Rate Curve of Roselle using Forced Convection Solar Cabinet Dryer

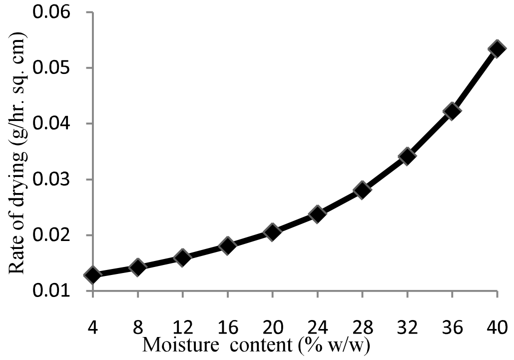

Figure (7) Drying Rate Curve of Roselle using Tray Dryer

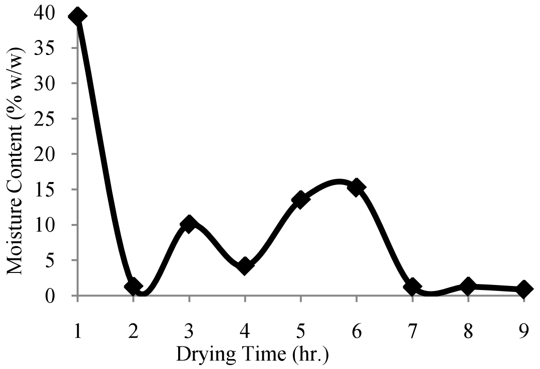

Figure (8) Drying Curve of Roselle by Sun Drying

Experiments were conducted to evaluate the performance of the solar dryers. Figure (4) shows the variation of temperature inside the solar dryers with respect to time without loading under sun radiation. The temperature measurement at the part of collector and inside the drying chamber of DSCD was 70°C and 60°C, respectively. For forced convection, the air blower was switched on and the velocity of air at inlet of the tray was measured with anemometer. The temperature at the collector filled with heat storage material (pebbles) and drying chamber of FCSCD was 65°C and 55°C, respectively. During day time, pebbles absorbed the heat energy. Temperature at inlet and outlet of the solar collector and drying chamber were measured at every one hour or 30 minutes interval.

Solar dryers generate higher temperatures and lower relative humidities than ambient conditions due to their trap radient energy on solar collector. Due to heated air, humidity is reduced and thus removal of moisture is increased, resulting in increased drying rates.

Table (1) Drying Condition of Solar Cabinet Dryer for Roselle

Location		University of Yangon	
Crop		Roselle	
Drying Period		Dec 2015-Feb 2018	
Maximum Drying Temperature in Dryer (°C)		~ 60	
Drying Time (hr.)		6	
Total Insolation (kWh/m^2/day)		6	
Items		Types of Dryer	
		DSCD	FCSCD
Ambient Air Temperature (°C)	High	34.5	31.2
	Low	22.5	17.4
	Mean	28.5	24.3
Ambient Air Relative Humidity	High	70	74
	Low	58	23
	Mean	64	49
Air Flow (ms^{-1})	High	0.3	0.8
	Low	0.1	0.5
	Mean	0.2	0.7
Weight or Moisture Content of Batch (g)	Start	200	200
	End	22.22	20.36
Pick up Efficiency (%)		3.15	17
Collection Efficiency (%)		0.02	0.004
System Drying Efficiency (%)		2.41	2.41

Table (2) Effect of Concentration of Sodium Metabisulphite on Organoleptic properties of Dried Roselle using Solar Cabinet Dryer

Weight of roselle	- 100g
Immersing time	-15 min.
Volume of sodium metabisulphite solution	-1000 ml
Drying time	-5 hr.
Drying temperature	-55°C

No.	Sodium metabisulphite (% w/v)	Dried roselle		Remarks
		Color	Texture	
1	0.05	Yellowish brown	Crispy	Change in color and texture within 30 days
2	0.1	Yellowish brown	Crispy	Change in color and texture within 30 days
3	0.15*	Pale brown	Crispy	No change in color and texture up to three months
4	0.2	Pale brown	Crispy	No change in color and texture up to three months
5	0.25	Pale brown	Crispy	No change in color and texture up to three months

*Most suitable condition

Table (3) Effect of Concentration of Ascorbic Acid on Organoleptic Properties of Dried Roselle using Solar Cabinet Dryer

Weight of roselle	- 100g
Immersing time	-15 min.
Volume of Ascorbic acid solution	-1000 ml
Drying time	-5 hr.
Drying temperature	-55°C

No.	Ascorbic acid (% w/v)	Organoleptic Properties		Remarks
		Color	Texture	
1	0.05	Yellowish brown	Crispy	Change in color and texture after 30 days
2	0.10	Yellowish brown	Crispy	Change in color and texture after 30 days
3	0.15	Yellowish brown	Crispy	Change in color and texture after 30 days
4	0.20*	Greenish brown	Crispy	No change in color and texture up to three months
5	0.25	Greenish brown	Crispy	No change in color and texture up to three months

Table (4) Effect of Immersing Time of Ascorbic Acid on Organoleptic Properties of Dried Roselle using Solar Cabinet Dryer

Weight of roselle	- 100g
Volume of 0.2 % ascorbic acid solution	- 1000 ml
Drying time	- 5 hr.
Drying temperature	-55°C

No.	Immersing time (min.)	Organoleptic Properties		Remarks
		Color	Texture	
1	15	yellowish brown	Crispy	Change in color and texture after 30 days
2	30	Greenish brown	Crispy	Change in color and texture after 30 days
3	45	Greenish brown	Crispy	No change in color and texture up to 30 days
4	60*	Brownish green	Crispy	No change in color and texture up to three months
5	75	Brownish green	Crispy	No change in color and texture up to three months

Table (5) Effect of Concentration of Sodium Bicarbonate on Organoleptic Properties of Dried Roselle using Solar Cabinet Dryer

Weight of roselle	- 100g
Immersing time	- 5min.
Volume of Sodium Bicarbonate solution	- 1000 ml
Drying time	- 5 hr.
Drying temperature	- 55°C

No.	Sodium Bicarbonate (% w/v)	Organoleptic Properties		Remarks
		Color	Texture	
1	0.05	Greenish brown	Crispy	Change in color and texture after 30 days
2	0.10	Greenish brown	Crispy	Change in color and texture after 30 days
3	0.15*	Brownish green	Crispy	No change in color and texture up to three months
4	0.20	Brownish green	Crispy	No change in color and texture up to three months

The initial moisture content (wb) of fresh roselle in DSCD and FCSCD was 89.36% and 90% and then reduced to 10.64% after 4.5 hr. and 10% after 5 hr. of drying time. Figures (5) and (6) represent the drying rate curve of both drying conditions. From the results of Table (1), pick-up efficiency of FCSCD is higher than DSCD because of forced circulation of air can carry more heat from collector but system drying efficiencies of both dryer are same.

Experiments were done by varying the ratio (% w/v) of sodium metabisulphite, and ascorbic acid and sodium bicarbonate based on immersing time variation and the effect of those additives on organoleptic properties were determined. The results obtained were 0.15 (% w/v) of sodium metabisulphite, 0.2 (% w/v) of ascorbic acid, 0.15 (% w/v) of sodium bicarbonate for roselle.

Based on the optimum concentration of additives, Tables (4) and (6) pointed out 60 minutes and 45 minutes were the optimum immersing time for ascorbic acid and sodium bicarbonate. From the results of Table (7), dried roselle in DSCD was most suitable condition according to its organoleptic properties.

Table (6) Effect of Immersing Time of Sodium Bicarbonate on Organoleptic Properties of Dried Roselle using Solar Cabinet Dryer

Weight of roselle	-100g
Volume of 0.15 % sodium bicarbonate solution	-1000 ml
Drying time	-5 hr
Drying temperature	-55°C

No.	Immersing time(min.)	Organoleptic Properties		Remarks
		Color	Texture	
1	15	Greenish brown	Crispy	Change in color and texture after 30 days
2	30	Greenish brown	Crispy	Change in color and texture after 30 days
3	45*	Brownish green	Crispy	No change in color and texture up to three months
4	60	Brownish green	Crispy	No change in color and texture up to three months

Table (7) Effect of Dryer Types on Organoleptic Properties of Roselle

No.	Drying Modes	Organoleptic Properties		Remarks
		Color	Texture	
1	FCSCD	Greenish brown	Crispy	No change in color and texture within three months
2	DSCD*	Brownish green	Fluffy	No change in color and texture within three months
3	TD	Brownish green	Crispy	No change in color and texture within three months
4	SD	Yellowish brown	Fluffy	Change in texture within 30 days but no change in color

Table (8) Effect of Dryer Types on Rehydration Ratios of Dried Roselle

Weight of dried roselle	- 3g
Volume of water	- 100 ml

No.	Drying Modes	Rehydration Ratios				
		Rehydration Time (min.)				
		15	30	45	50	75
1	FCSCD	2.38	2.44	2.79	2.86	3.22
2	DSCD*	2.53	2.77	2.86	2.91	3.26
3	SD	2.21	2.41	2.53	2.63	2.83
4	TD	2.00	2.06	2.06	2.22	2.4
5	Commercial (Myanmar pyi thar)	2.57	2.64	2.66	2.82	2.82

Table (9) Physico-chemical Properties and Nutritional Value of Roselle

No.	Characteristics	Fresh Roselle	Dried Roselle				Commercial (Myanmar pyi thar)
			Types of Dryer				
			FCSCD	DSCD	TD	SD	
1	Moisture content (%w/w)	90.03	16.11	16.54	17.98	12.37	15.62
2	Ash content (%w/w)	0.83	5.33	5.17	4.58	7.96	6.18
3	Crude fiber content (%w/w)	1.47	15.47	15.53	9.07	11.56	9.36
4	Crude protein content (%w/w)	2.95	30.51	30.46	24.98	23.16	13.34
5	Crude fat content (%w/w)	0.22	2.86	2.83	1.88	2.02	2.4
6	Carbohydrate (%w/w)	4.5	29.72	29.92	41.51	42.93	53.10
7	Energy value (Kcal)	34	266.66	258	286	282	282
8	pH	2.7	5.6	4.8	5.5	5.9	5.8
9	Color intensity	0.87	0.72	0.75	0.76	0.65	0.77

Table (10) Minerals and Heavy Metals Composition of Roselle

No.	Constituents	Fresh (ppm)	Dried Roselle (ppm)				Limit of Detection (ppm)
			Types of Dryer				
			DSCD	FCSCD	TD	SD	
1	Sodium	7.49	5.72	5.61	5.97	5.58	0.002
2	Potassium	6.29	4.64	4.52	4.96	4.25	0.002
3	Calcium	11.58	9.29	9.30	9.48	9.18	0.002
4	Manganese	< LOD	< LOD	< LOD	< LOD	< LOD	0.009
5	Magnesium	9.54	6.69	6.58	7.12	6.54	0.0002
6	Zinc	< LOD	< LOD	< LOD	< LOD	< LOD	0.013
7	Iron	8.78	6.42	6.47	6.81	6.25	0.006
8	Arsenic	< LOD	< LOD	< LOD	< LOD	< LOD	0.026
9	Lead	< LOD	< LOD	< LOD	< LOD	< LOD	0.015
10	Cadmium	< LOD	< LOD	< LOD	< LOD	< LOD	0.007

LOD: Limit of Detection

Table (8) shows that dried roselle in DSCD was higher rehydration ratios ranging from 2.53-3.26 than other methods and also commercial.There was a little difference of rehydration ratios among all the methods.

Table (9) tabulate the physico-chemical properties and nutritional value of fresh and dried roselle and compared with commercial brand (Myanmar pyi thar). By comparing dried sample and commercial brand, moisture content, ash content and carbohydrate present in roselle dried in both dryers were found to be less than that of commercial therefore their energy value is less than commercial brand.

According to Table (10), calcium was the most abundant mineral in fresh and dried roselle and iron and magnesium were the second most abundant. The lowest mineral value was potassium in fresh and all dried samples. All minerals reduced due to drying but manganese and zinc absent. The water activities of dried roselle were nearly the same by using DSCD, FCSCD, TD and SD as shown in Table (11). It was less than 0.65 therefore yeast, mold and bacteria could not grow.

Table (12) shows the load of yeast and mold in all dried roselle samples were slightly lower population. This could be attributed to the lower pH of these products.From the results of the examination of residual pesticides in roselle, there are no residual pesticides in all samples.

The rehydrated roselle was prepared as soup and the sensory evaluation results are shown in Table (13). Higher average scores of appearance, color and texture were observed and overall acceptability was 8.2.

Table (11) Water Activity of Roselle

No.	Items	Equilibrium Relative Humidity (%)	Water activity (a_w)
1	Fresh	78	0.78
2	DSCD	36	0.36
3	FCSCD	38	0.38
3	TD	35	0.35
4	SD	40	0.40

Table (12) Microorganisms in Dried Roselle

No.	Microorganisms	Dried Roselle			
		DSCD	FCSCD	TD	SD
1	Yeasts and molds (cfu)	1.1×10^3	1.2×10^3	1.2×10^4	2.5×10^2
2	Salmonella (cfu)	ND	ND	ND	ND
3	Coliform (cfu)	ND	ND	ND	ND

cfu: Colony Forming Unit, ND : Not Detected

Table (13) Sensory Evaluation for Roselle Soup

No.	Organoleptic Properties	Average Scores
1	Appearance	8.4
2	Color	8.2
3	Texture	8.0
4	Overall Acceptability	8.2

Fig (9) Fresh Roselle

Fig (10) Roselle Dried by using DSCD

Fig (11) Roselle Dried by using FCSCD

Fig (12) Roselle Dried by using TD

Fig (13) Roselle Dried by using SD

Fig (14) Rehydrated Roselle

Fig (15) Roselle Soup

IV. CONCLUSION

The performance of distributed solar cabinet dryer (DSCD) and forced convection solar cabinet dryer (FCSCD) was evaluated. The use of solar cabinet dryers led to considerable reduction in drying time in comparison to sun drying. FCSCD with heat storage material enables to maintain consistent air temperature inside the dryer and the inside temperature in

FCSCD was higher than in DSCD. Besides that the inclusion of heat storage materials in FCSCD enlarge the duration of drying about 0.5-1 hr. per day than using DSCD after sunset. Both dryers can remove more moisture in first tray (lowest tray) than other trays because it can attain more hot air from the absorber and get the chance of moisture diffusion from both side of the tray with low relative humidity.

In all drying modes, the higher moisture reduction during the initial stages of drying was observed due to the evaporation of free moisture from the outer surface layers and then reduced due to internal moisture migration from inner surface layers to the surface, which results in a process of uniform dehydration. Drying rate decreased with increased in drying time and decreased in moisture content. In the initial stage of falling rate period, drying rate decreased with fall in moisture content and became very slow in later stages. The factors affecting the drying rate of roselle were air temperature, relative humidity, air velocity and initial moisture content of the product.

Roselle treated with 0.2 (% w/v) ascorbic acid solution and immersing time 60 minutes was the most favorable condition based on the organoleptic properties. It was observed that immersing time of 45 minutes in 0.15 (% w/v) of sodium bicarbonate solution could maintain more chlorophyll content in the dried roselle. The final moisture content of roselle was about 10% after 3 hr. and 4.5 hr. in the solar cabinet dryer integrated with and without storage materials.

It was observed that in all drying methods, the rehydration ratio was increased with increased in soaking time. Roselle dried in DSCD has higher rehydration ratio than the other three methods.

For both experiments, it can be concluded that although the drying function of FCSCD is faster than DSCD, the texture of dried product obtained by using FCSCD was very hard compare to that using DSCD. Therefore DSCD was chosen as the suitable dryer to be used based on quality of dried products and economic point of view of electricity used.

From the view point of physico-chemical properties and nutritional values, it is clear that solar dried products using solar cabinet dryer have higher nutritional value in comparison to open sun dried products. The quality of product depended upon the removal of moisture during drying process.

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